COLLINGWOOD HARBOUR

REMEDIAL ACTION PLAN

SEDIMENT BIOASSAYS AND SEDIMENT CORE CHEMISTRY COLLINGWOOD HARBOUR 1988 - 1989

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SEDIMENT BIOASSAYS AND SEDIMENT CORE CHEMISTRY, COLLINGWOOD HARBOUR 1988 - 1989

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FORWORD

In its 1985 report to the International Joint Commission (IJC), the Great Lakes Water Quality Board recommended that the appropriate jurisdictions prepare and submit detailed Remedial Action Plan (RAPs) for the restoration of beneficial uses of 42 identified "Areas of Concern" on the Great Lakes system. Collingwood Harbour is one of the "Areas of Concern.

The process of developing a RAP for Collingwood Harbour was initiated in 1986 with the formation of a Federal/Provincial RAP team to oversee preparation of the RAP.

The RAP team in its March 1989 Stage I report defined restrictions on dredging as an impairment of Collingwood Harbour beneficial uses. This technical report provides further information on the biological significance of trace metals and PCBs in sediment that are at concentrations that exceed the Ontario Ministry of the Environment dredging guidelines for open water disposal of dredged materials. In developing remedial options for sediment further site-specific biological assessment was required. This report presents the results of chronic sublethal toxicity tests conducted on Collingwood Harbour sediment and sediment core chemistry.

It should be noted that this report is only intended to serve as a background reference document. It provides useful information that will assist the RAP team and the public in evaluating options and in ultimately defining a remedial action plan for the harbour. The results will be incorporated into the Stage II report for the Collingwood Harbour RAP.

1 SUMMARY:

In 1986 sediment bioassays using mayfly nymphs (Hexagenia limbata) and juvenile fathead minnows (Pimephales promelas) demonstrated that sediment from Collingwood Harbour was not lethal during acute exposure intervals (MOE 1989). In a limited number of samples lead residues in bioassay organisms were elevated relative to control organisms, resident infauna, and introduced mussels. The potential for chronic sublethal toxicity was apparent. It was unclear as to whether the elevated lead levels in the absence of toxicity were due to artifacts associated with bioassay design, or whether sublethal toxicity was a potential threat to benthic organisms.

In November 1988 sediment collection was repeated and bioassay design revised in order to address several hypotheses. The primary hypothesis was that deeper sediment could be more contaminated than surficial sediment so that organisms exposed to sediment in the laboratory that included deeper materials were in fact exposed to higher metal concentrations than *in situ*. An alternate or additional hypothesis was that the organisms used in the bioassays were not sufficiently sensitive for the detection of nonlethal effects of contaminants. The 1988 study examined the combined importance of bioassay duration, organism sensitivity, and surficial (as opposed to bulk) sediment chemistry for three endpoints; growth, mortality and bioaccumulation. In addition, cores were collected to a depth of 18-20 cm and analyzed at 2 cm intervals to reveal whether chemical gradients were apparent in the sediment.

Concurrent with these studies, additional sediment was collected in proximity to the confined disposal facility and the shipyard's property, aimed at revealing the presence or absence of chemical gradients from these two potential sources.

Sediment collected at the shipyards had concentrations of Zn and Pb that would be of concern if this material was acting as a source to the harbour. While the sediment appears to be contained, any activity that would result in the remobilization of this material should be discouraged.

Sediment bioassays using sensitive endpoints indicate no impacts of harbour sediment on the biota as measured by mortality and growth. The elevated Pb residues measured in the 1986 bioassays were not observed in this study. Tissue residues of Pb and other contaminants were comparable to concentrations observed in organisms collected from lakes remote from contaminant sources. No significant mortality occurred, and mayfly and fathead minnow growth in harbour sediment equalled or exceeded that of controls. This information, coupled with 1986 field observations on tissue residues in native benthic invertebrates, sculpins, sport fish and introduced biomonitors (mussels) provide multiple lines of evidence that support the conclusion that concentrations of biologically available trace metals in Collingwood Harbour sediment are not of toxicological significance.

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2 INTRODUCTION:

In 1986, sediment bioassays using mayfly nymphs (Hexagenia limbata) and juvenile fathead minnows (Pimephales promelas) demonstrated that sediment from the Harbour was not lethal during acute exposure intervals (MOE 1989). In a limited number of samples, however, lead residues in bioassay organisms were elevated relative to controls, resident infauna, and introduced mussels. While acute toxicity was not of concern, the question of elevated Pb residues in test organisms and potential for chronic sublethal toxicity was apparent. Due to the bioassay protocol used at that time, it was unclear as to whether the apparently anomalous results were due to artifacts associated with the test, or whether sublethal toxicological properties of the sediment were a potential threat to benthic organisms.

In November 1988 sediment collection was repeated and bioassay design revised in order to address several hypotheses, as follows:

The 1986 sediment bioassay was conducted using bulk sediment, that is, the entire contents of replicate ponar grabs were homogenized and air sieved through a 2 mm mesh prior to bioassay assembly. Tests run with surficial sediment could yield different responses.

(a) The first hypothesis was that deeper sediment could be more contaminated than surficial sediment. If this was the case, native infauna and introduced biomonitors would be exposed to cleaner sediment than were bioassay organisms.

The 1986 bioassay organisms were second year old mayfly nymphs and 4 to 5 month old juvenile fathead minnows, the latter weighing approximately one gram wet weight per individual. Tests were run as 10 day static beaker tests with mortality and bioaccumulation as the endpoints.

(b) An alternate or additional hypothesis was that by using organisms at this stage of development, the bioassays were not sufficiently sensitive to detect nonlethal effects of contaminants.

(c) In addition, a nonlethal endpoint such as growth has been shown to be a more responsive indicator of toxicity than mortality. Inclusion of this endpoint was considered to be advantageous.

The 1988 study examined the combined importance of bioassay duration, organisms sensitivity, and surficial as opposed to bulk sediment chemistry for three endpoints; growth, mortality and bioaccumulation.

A second component to the study was to investigate contaminant profiles in sediment.

(a) Sediment cores were sectioned to a depth of 18-20 cm and analyzed at 2 cm intervals to reveal whether chemical gradients were apparent.

(b) Additional sediment collections in proximity to the confined disposal facility and the Shipyard's property were aimed at revealing the presence or absence of chemical gradients from these two potential sources.

3 MATERIALS AND METHODS

3.1 Sediment bioassays

A 21 day static sediment bioassay was conducted using mayfly nymphs and juvenile fathead minnows. Growth, mortality, and bioaccumulation of trace metals and PCBs was recorded. A Ministry of the Environment protocol (Lomas and Krantzberg 1988) was modified to increase exposure duration and to include more sensitive life stages and endpoints, thus providing for the measurement of sediment toxicity and demonstration of contaminant transfer from sediment to benthos and water column organisms, if this phenomenon was to occur.

Bioassays were conducted on sediment from each of the stations (Figure 1). Bulk and surficial sediment was collected by Ponar grab. The surface 5 cm was removed from each grab using acid-washed polyethylene spoons or glass beakers. Ten litres of bulk or surficial sediment were placed in plastic lined collection buckets which were then sealed, kept cold in the field, and stored at 4 C for a maximum of two weeks. Intact sediment cores were retrieved by SCUBA divers using acid-washed and hexane- and distilled water-rinsed acrylic cores of comparable diameter to the test beakers.

In the laboratory, sediment was air-sieved through a 2 mm mesh to remove large particles, stones and other debris, and was then thoroughly homogenized. For the bulk and surficial sediment bioassays, 2 L glass widemouth jars, acid washed and hexane rinsed, were filled to a depth of 3 cm with sediment (surface area = 100 cm^2). Dechlorinated water was gently added at a ratio of 4:1 water to sediment (v:v). Care was taken to avoid having sediments adhere to the glass above the 3 cm level. Resuspended sediment was allowed to settle for 24 hours, after which the overlying water was aerated for 1 hour by inserting airlines through the lids of the glass jars and securing the lids in place. Water loss due to evaporation was replaced as necessary in order to maintain a water to sediment ratio of 4:1. pH and dissolved oxygen in the overlying water were monitored routinely for the duration of the experiment.

For the intact cores, overlying water was removed by siphon and replaced with dechlorinated tap water. This enhanced comparability with the beaker experiments

and eliminated the potential for source water to act as a contributor to toxicity, thereby confounding the determination of sediment as a source of contaminants.

Organisms for the experimental bioassays were three to four month old juvenile fathead minnows (Pimephales promelas) (acquired from Ministry of the Environment Rexdale laboratory cultures) weighing approximately 0.5 gm wet weight and first year mayfly nymphs (Hexagenia limbata) weighing about 30 mg wet weight, collected at a clean reference site (Honey Harbour, Georgian Bay, Ontario).

Several hours prior to experimental exposure, mayflies were removed from their holding aquaria by sieving small volumes of sediment through a 500 um mesh. Nymphs were randomly allocated to beakers containing dechlorinated water until each beaker had 10 individuals of similar size (c.a. 30 mg/ individual, wet weight). The nymphs were weighed after blotting them on several layers of "Kim Wipes" or acid rinsed filter papers to remove adhering water. Similarly, juvenile fathead minnows were randomly allocated to beakers containing dechlorinated water until each beaker had 10 individuals of similar size (c.a. 0.5 gms/individual, wet weight). Wet weight of each group of 10 individuals was measured.

Triplicate jars of each bioassay organism were assembled and organisms were added when 24 hours of settling followed by 1 hour of aeration had elapsed. Aeration persisted for the duration of the 21 day exposure interval. All control and test jars were maintained at 20 C by the use of a water bath and experiments were conducted at ambient light.

During the 21 day bioassay period mortality was noted and dead organisms were removed. At day 21 organisms were removed from the bioassay jars by passing the entire contents of each jar through a 500 um sieve and retrieving the biota. Recoveries were noted and the remaining organisms were reweighed and measured using the procedure described above.

Where biomass was insufficient for metal analysis, the biota for the triplicate beakers were pooled. Minnows and mayflies were not pooled together. Sediment from Honey Harbour, from which the mayflies were collected, and a station in Nottawasaga Bay were used for controls. Mortality of organisms in control sediment was not to exceed 10%, a value widely recognized in the literature as sufficiently low to account for organism damage due to handling, and not necessarily indicative of toxicity.

3.2 Sediment core profiles:

Cores were collected from two of the bioassay stations (stations 20 and 21) and sectioned in 2 cm intervals for metal, nutrient, and physical analysis according to Ontario Ministry of the Environment standard protocols (MOE 1983). In addition, sediment from one transect of 4 stations in the vicinity of the Canadian Shipyard's dry docks and sediment from one transect of 5 stations around the perimeter of the confined disposal facility were cored to determine the extent to which contaminants were retained within both these structures (Figure 1). These were sectioned following visual inspection according to distinct observable layers.

4 RESULTS

4.1 Sediment bioassays

Mortality

Collingwood Harbour sediment was not lethal to mayfly nymphs (Hexagenia limbata) or to juvenile fathead minnows (Pimephales promelas). Mayfly mortality ranged from 0 to 13% (Table 1) and there was no apparent pattern with respect to bioassay design. No fathead minnow mortality was observed. Analysis of variance revealed that values were not significantly different from 10%, a value which current protocols have set as acceptable for control mortality.

Table 1: Mayfly mortality (%) in sediment bioassays conducted using surficial sediment, bulk sediment, and intact sediment cores (n.a=not applicable).

STATION	SURFICIAL SEDIMENT	BULK SEDIMENT	INTACT CORES
HONEY HARBOUR (control	0	n.a.	n.a.
NOTTAWASAGA BAY (387)	10	n.a.	n.a.
20 (Collingwood Harbour)	3	13	13
21 (Collingwood Harbour)	7	7	7

Growth:

At station 21, mayflies gained more weight in the intact sediment cores than in the bulk and surficial sediment. Biomass differences were not significant at station 20 (Figure 2). In general, fathead minnows tend to lose weight in this static beaker design of the sediment bioassay since food is withheld and nutrients can only be acquired via sediment ingestion (Krantzberg 1990). Nevertheless, for station 21 fathead minnows maintained their weight in the intact sediment cores and analysis of variance (ANOVA) confirmed that significantly less weight was lost in station 20 core tube exposures compared

to controls and to other treatments (Figure 3). All other treatments resulted in biomass loss that did not differ significantly from controls ($p > 0.05$).

Bioaccumulation

Few differences were observed in tissue concentrations of trace metals in mayflies or fathead minnows as a function of exposure to bulk, surficial, or intact sediment (Table 3,4). PCB residues in bioassay organisms were consistently lower in intact core treatments than in the bulk and surficial sediment treatments (Table 3, 4). Lead concentrations in mayflies were variable and exceeded those of controls, however, the elevated concentrations measured in the 1986 bioassay at these stations were not reproduced. Lead concentrations of 1 to 3 $ug.g^{-1}$ wet weight are comparable with the resident infauna tissue residues measured in 1986 (4 - 5 $ug.g^{-1}$) and are lower than values which have been observed for remote shield lakes (Krantzberg and Stokes 1988). Lead concentrations of 0.5 - 3.0 $ug.g^{-1}$ wet weight in fathead minnows were within the range observed for sculpins collected from the harbour in 1986 (0.2 - 5.9).

4.2 Sediment core profiles

Bioassay stations

Lead profiles in sectioned cores from stations used in the bioassays (Figure 4) showed a pronounced augmentation of Pb concentrations with depth at station 21. Copper (Figure 5) also tended to increase with depth. Other metal profiles were fairly stable for stations 20 and 21, and at station 21, total phosphorus and total Kjeldahl nitrogen (TKN) were at higher concentrations in surficial sediment and decreased with depth (Table 2). Despite its proximity to the Shipyards, at station 21 Zn was only marginally above the Ontario Ministry of the Environment's draft "lowest effects level" of 120 $ug.g^{-1}$. The lowest effects level for Pb is 31 $ug.g^{-1}$. This is the concentration at which at least 95% of the biota are likely to be protected, based on a basin wide analysis of the presence of organisms in comparison with sediment chemistry.

Transect stations

The transect locations for the confined disposal facility (C1 - C5) and the Shipyards (S1 - S4) are illustrated in Figure 1. No tin was detected in sediment from cores collected in the vicinity of the Shipyard's dry docks. Lead and Zn concentrations in some of the sediment cores within 50m of the of the Shipyard's concrete walls approached the draft Ontario Ministry of the Environment (MOE) "limit of tolerance" guidelines of 250 and 820 $ug.g^{-1}$ respectively (Persaud et al. 1990) (Figure 6). This is the concentration at which adverse biological effects are highly probable. No consistent depth gradients were apparent. For each element, deeper sediment had either greater, lesser, or comparable concentrations. Note that station 21 is in the vicinity of the Shipyard's property and sediment from that station revealed no adverse biological impacts as measured by growth and survival.

At some stations in the vicinity of the confined disposal facility (Figure 7), total organic carbon, total phosphorus, Cr, Cu, Pb, Mn, and Zn exceeded the Ontario Ministry of the Environment draft sediment guidelines for the "lowest effects level". No depth gradients were detected. Site specific biological testing at station 20, in proximity to the transect stations and of comparable chemistry found no effects of sediment on growth and survival.

It is worth recognizing that these concentrations (limit of tolerance, lowest effects level), while biologically based, rely on bulk chemistry collected across the entire Great Lakes basin. Due to the uncertainty surrounding site specific differences in physical, chemical and biological properties, the values are acknowledged to be guidelines that require that biological effects be confirmed or refuted at the local scale. This is accomplished, in part, through sediment bioassessment.

5 DISCUSSION

Biologically based sediment quality guidelines are under development by the Ontario Ministry of the Environment. These guidelines will, in part, provide the basis for making decisions on remedial actions (Persaud et al 1990). The guidelines identify a No-Effect Level (NEL), a Lowest Effects Level (LEL) at which sediment is considered as having the potential to impair the aquatic environment, and a Limit of Tolerance (LOT) level, at which it is highly likely that a sediment will have significant effects on biota. When bulk chemistry exceeds the LEL, the draft guidelines recommend that biological testing be conducted. This is due to the fact that the guidelines were derived for the Great Lakes basin in general and do not attempt to address local variations in physical, chemical and biological properties on a site specific basis. In addition there is considerable uncertainty surrounding the actual biological effects that can be expected based on bulk chemical concentrations of contaminants in sediment. The chemical values, then, can be viewed as indicators of the need for specific assessment and remediation requirements.

The use of biological information in evaluating sediment is crucial, as it is well recognized that the susceptibility of biological organisms to trace metal contamination varies among aquatic environments. Luoma (1983), Tessier et al (1984), Campbell et al (1987) and Krantzberg (1989) have shown that an important factor in metal toxicity is the manner in which sediment geochemistry alters biological availability of trace elements. Unfortunately, the interactions among the wide array of biological and physicochemical processes which govern metal accumulation and subsequent toxicity are not understood to the point of being moulded into predictive models.

While research continues to lead to improvements in methods for determining metal distribution among biologically important and biologically inactive sediment components, and continues to enhance our understanding of physiological processes involved in metal metabolism, there is a need to include biological assessment of sediment in conjunction with chemical measurements.

Chapman (1989) has recommended that an integrated strategy for sediment management be adopted that includes criteria based on biological effects observed both in the laboratory and in nature. Similarly, Van de Guchte et al (1988) identify a suite of biological test methods that provide an integrated approach to the determination of the toxicological qualities of sediment contaminated with a variety and sometimes unknown chemicals.

The sediment bioassays conducted in this study provide information on whether exceeding the LEL for some parameters is of toxicological significance. The most sensitive endpoint in the Collingwood Harbour bioassays was the growth response of mayfly nymphs. Growth inhibition bioassays have been used as sensitive indicators of nonlethal toxicity in chronic bioassays (Nebeker et al. 1984, Powlesland and George 1986, Brungs et al 1976, Krantzberg 1990). An absence of growth inhibition is one line of evidence that indicates sediment is not eliciting toxicity.

Mayflies and fathead minnows exposed to Collingwood Harbour sediment grew as well as or better than control organisms. In particular, the intact core bioassays resulted in substantially improved growth for fathead minnows. The same was true for mayflies at station 21. This improvement may be related to the Pb profile observed in station 21 sediment. Deeper sediment had higher concentrations of Pb than surficial sediment. Exposure to intact surface sediment may have improved growth due to exposure to lower concentrations of Pb.

The 1986 mussel biomonitoring and analysis of native benthic invertebrates (MOE 1989) support the laboratory findings on toxicity and bioaccumulation. No adverse effects of sediment on biota were observed in the 1986 studies. Tissue residues in bioassay organisms were within the range observed in native organisms, and were within concentrations cited in the literature for uncontaminated locations (Timmermans 1989, Tessier et al 1984, Krantzberg and Stokes 1988).

The sediment collected along transects at the CDF was of a chemical nature comparable to sediment at station 20. As a result of the physical process

involved in filling the CDF, a limited portion of dredged sediment can be resuspended during the removal operation and settles back to the bed sediment. Thus, some metals may be found at higher concentrations adjacent to the CDF due to the process of CDF filling. Sediment at the Shipyard's property has Zn and Pb at concentrations that approach the MOE draft sediment guidelines Limit of Tolerance. Metals concentrations in the sediment at station 21, approximately 100 m from the Shipyards are substantially lower than those within 50 m suggesting that the material is being contained at the Shipyard. Sediment at station 21 does not exert observable toxicity. Nevertheless, the sediment at the Shipyards property could pose a significant threat to the Harbour ecosystem in the event of any activities that would require removal or result in resuspension of sediment. Any movement of this sediment could be achieved safely if appropriate technology is employed.

6 CONCLUSIONS

Sediment samples collected at the Canadian Shipyards dry docks have concentrations of zinc and lead that would be of particular concern if this material was acting as a source to the harbour. Sediment at station 21, in close proximity to the Shipyard property does not elicit measurable toxicity. While the sediment appears, then, to be contained, any activity that would result in remobilization of this material should be discouraged.

Sediment bioassays using sensitive endpoints indicate no of observable impacts of harbour sediment on the biota. The elevated lead residues measured in organisms in the 1986 bioassays were not observed in this study. Currently, the significance of metal residues in biota to organism health is not well understood and comparisons of tissue residues with those of organisms from remote locations is a first step to evaluating potentials for biological effects. In the case of Collingwood Harbour, tissue residues of contaminants were comparable to concentrations observed in organisms colonizing uncontaminated sediment. No significant mortality occurred, and mayfly and fathead minnow growth in harbour sediment equalled or exceeded that of controls.

This information, coupled with 1986 field observation on native benthic invertebrates, sculpins, sport fish and introduced biomonitors (mussels) provides multiple lines of evidence that support the conclusion that concentrations of biologically available trace metals in Collingwood Harbour sediment are not of toxicological significance.

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8 GLOSSARY

acute	short term exposure
Al	aluminum
ANOVA	a statistical procedure
benthic	bottom, as in the bottom of a lake
benthos	organisms living at the bottom of a water body
bioassay	biological testing a specific substance
bioaccumulation	accumulation of a substance by an organism
bioavailable	a property that enables a substance to bioaccumulate
biomonitor	an organism used to monitor for environmental conditions
chronic	extended exposure duration
core	a sediment sample that is collected in a vertical tube
Cr	chromium
Cu	copper
endpoint	measured response at the termination of the bioassay
Fe	iron
geochemistry	geological and chemical properties of a material
infauna	organisms that live in sediment
in situ	in the environment, in nature
Mn	manganese
native	an indigenous organism
Ni	nickel
nonlethal	not causing death
P	phosphorus
Pb	lead
physicochemical	physical and chemical properties of a substance or environment
Ponar grab	a device for retrieving sediment
Sn	tin
static	as in static beaker test: no water circulation or renewal
TKN	a measure of biologically reactive nitrogen
transect	a line or row of sampling stations
Zn	zinc

9 ACKNOWLEDGEMENTS

The Collingwood Harbour RAP team acknowledges the valuable assistance provided by the former Aquatic Biology Section of the Ontario Ministry of the Environment in conducting the sediment bioassays and collecting cores at the bioassay stations. Public Works Canada under the lead of Mr. Ansar Kahn graciously provided sediment core collection and chemical analysis for the Shipyard and confined disposal facility transects. The Collingwood Harbour Public Advisory Committee, R.K. Sherman and D. Boyd provided helpful comments in their review of the manuscript.

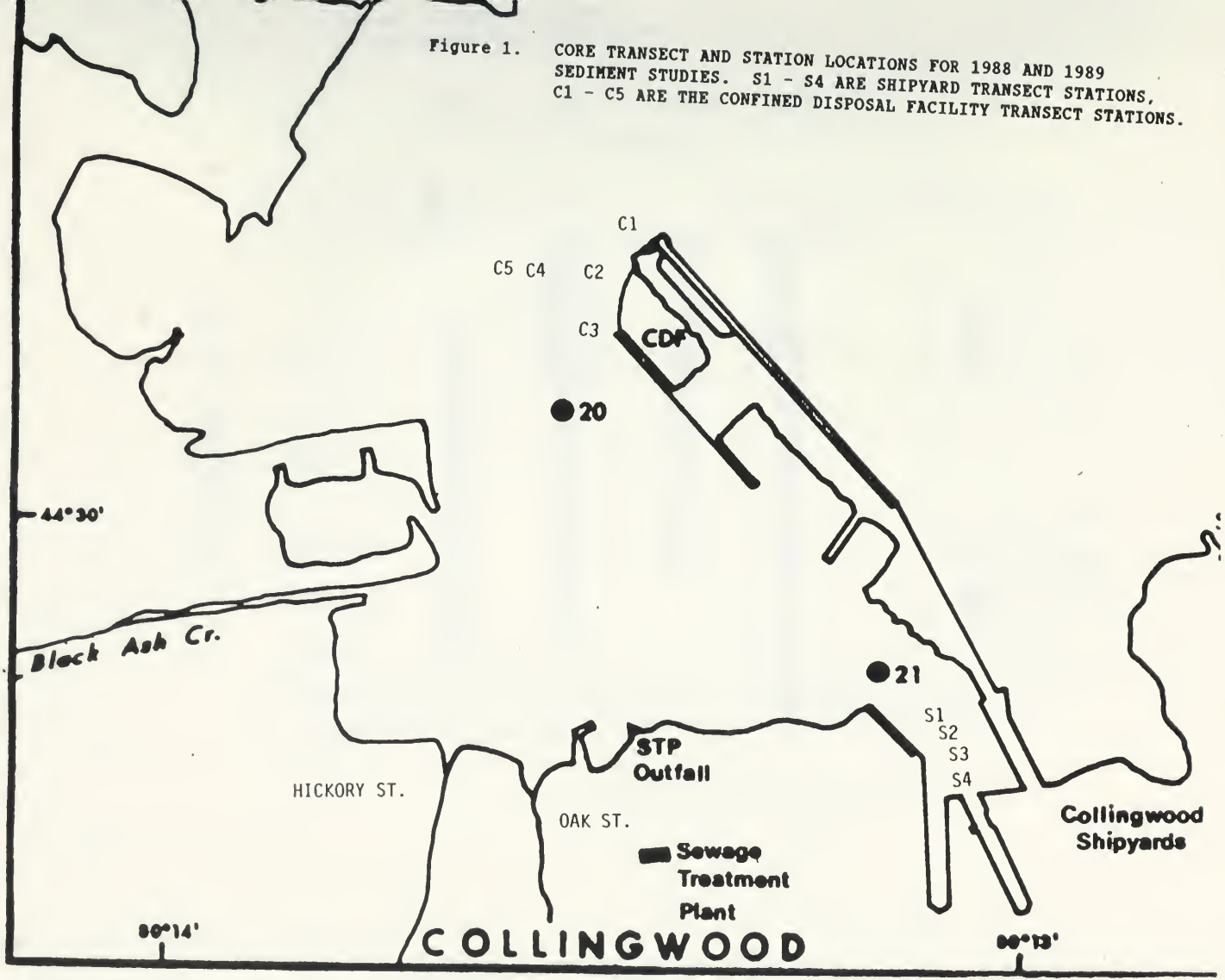
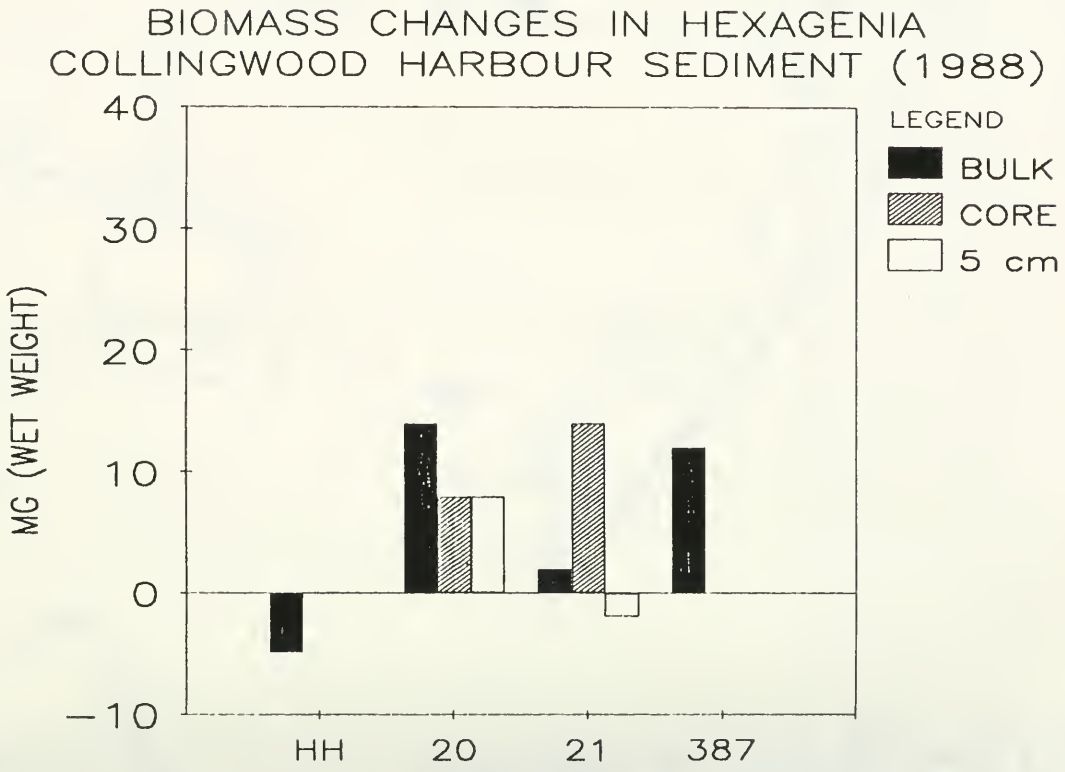


Figure 1. CORE TRANSECT AND STATION LOCATIONS FOR 1988 AND 1989 SEDIMENT STUDIES. S1 - S4 ARE SHIPYARD TRANSECT STATIONS, C1 - C5 ARE THE CONFINED DISPOSAL FACILITY TRANSECT STATIONS.

Figure 2.



HH refers to Honey Harbour control sediment.
(see text for explanation of legend)

Figure 3.

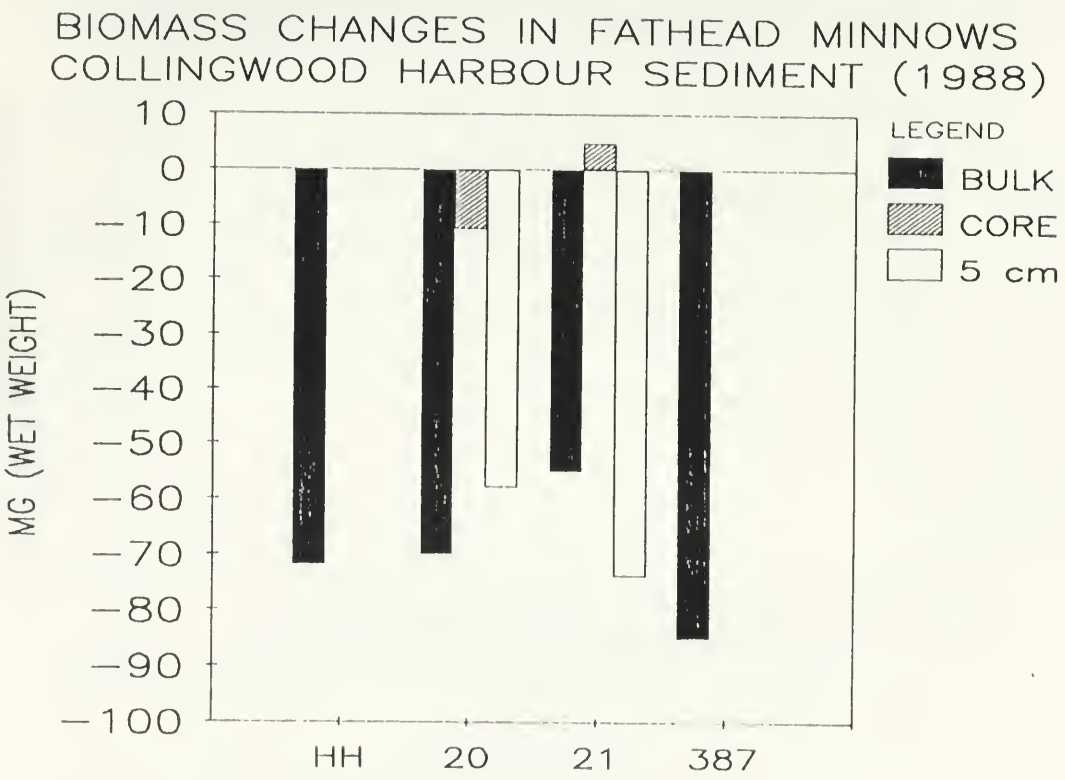

BIOMASS CHANGES IN FATHEAD MINNOWS
COLLINGWOOD HARBOUR SEDIMENT (1988)
MG (WET WEIGHT)
10
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
HH
20
21
387
LEGEND
BULK
CORE
5 cm

Figure 4.

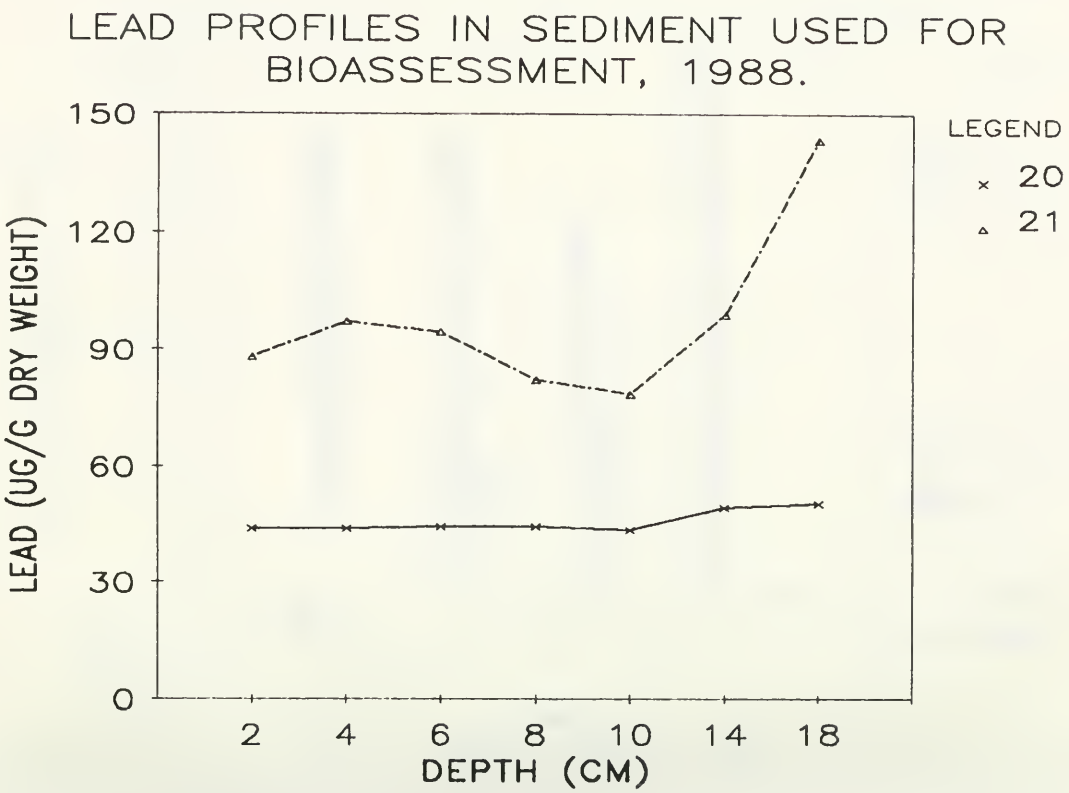

LEAD PROFILES IN SEDIMENT USED FOR BIOASSESSMENT, 1988.
LEAD (UG/G DRY WEIGHT)
150
120
90
60
30
0
2
4
6
8
10
14
18
DEPTH (CM)
LEGEND
20
21

Figure 5.

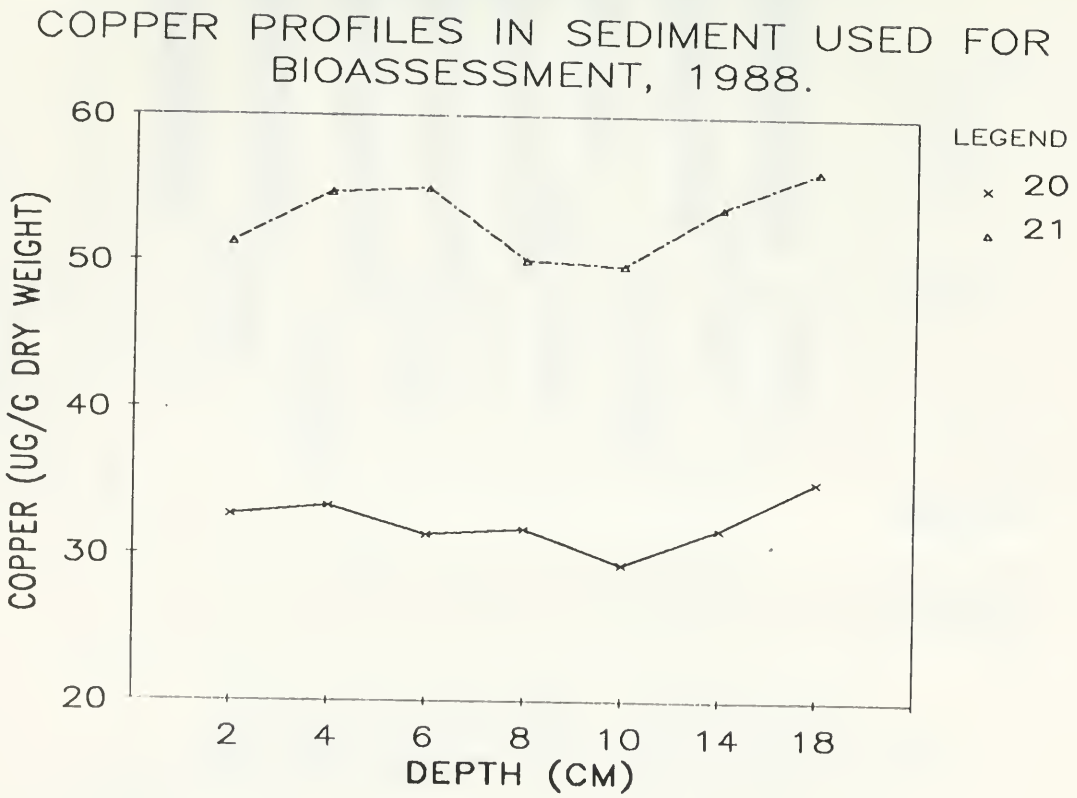

COPPER PROFILES IN SEDIMENT USED FOR BIOASSESSMENT, 1988.
COPPER (UG/G DRY WEIGHT)
60
50
40
30
20
2
4
6
8
10
14
18
DEPTH (CM)
LEGEND
20
21

FIGURE 6A

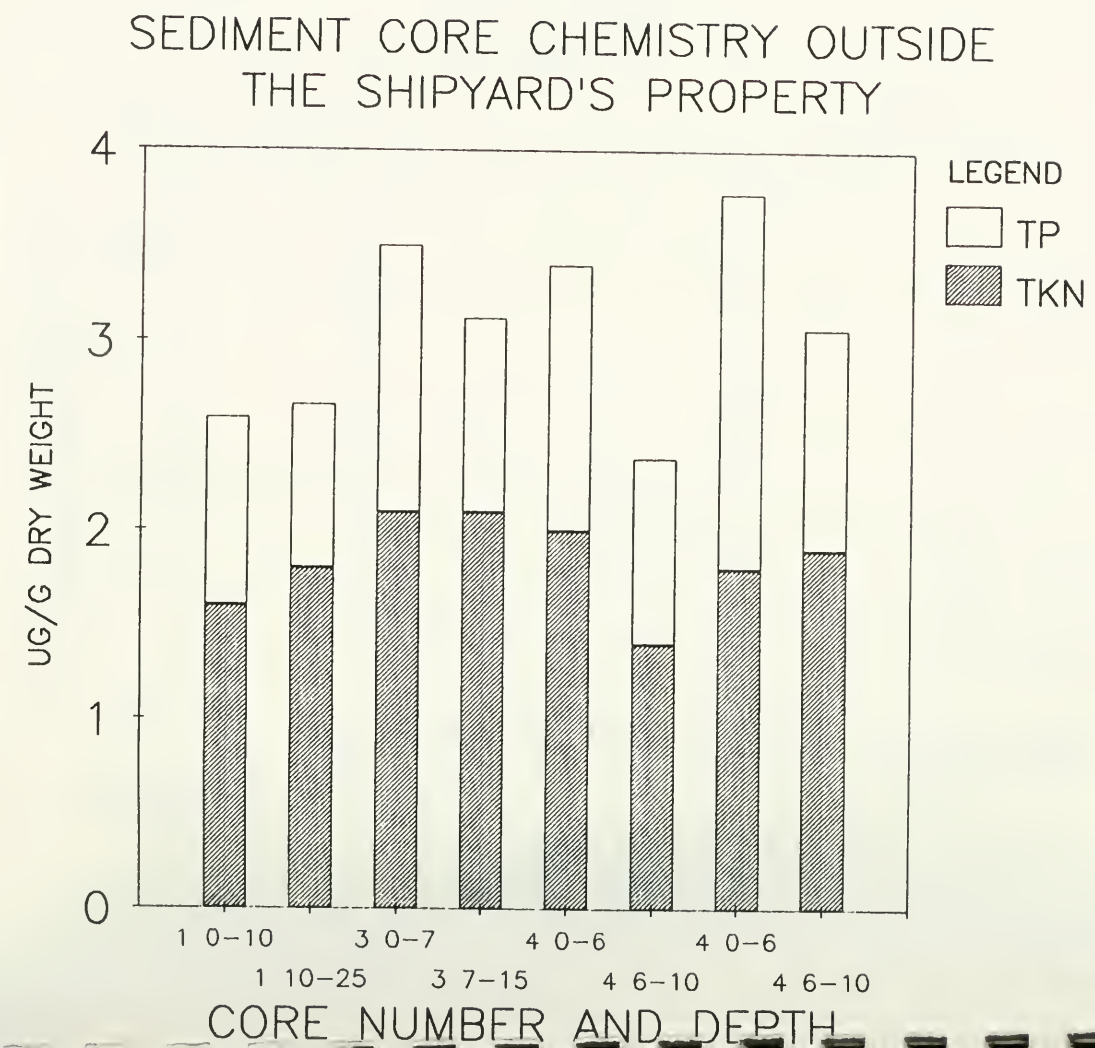

SEDIMENT CORE CHEMISTRY OUTSIDE
THE SHIPYARD'S PROPERTY
LEGEND
TP
TKN
UG/G DRY WEIGHT
0
1
2
3
4
1 0-10
1 10-25
3 0-7
3 7-15
4 0-6
4 6-10
4 0-6
4 6-10
CORE NUMBER AND DEPTH

FIGURE 6B

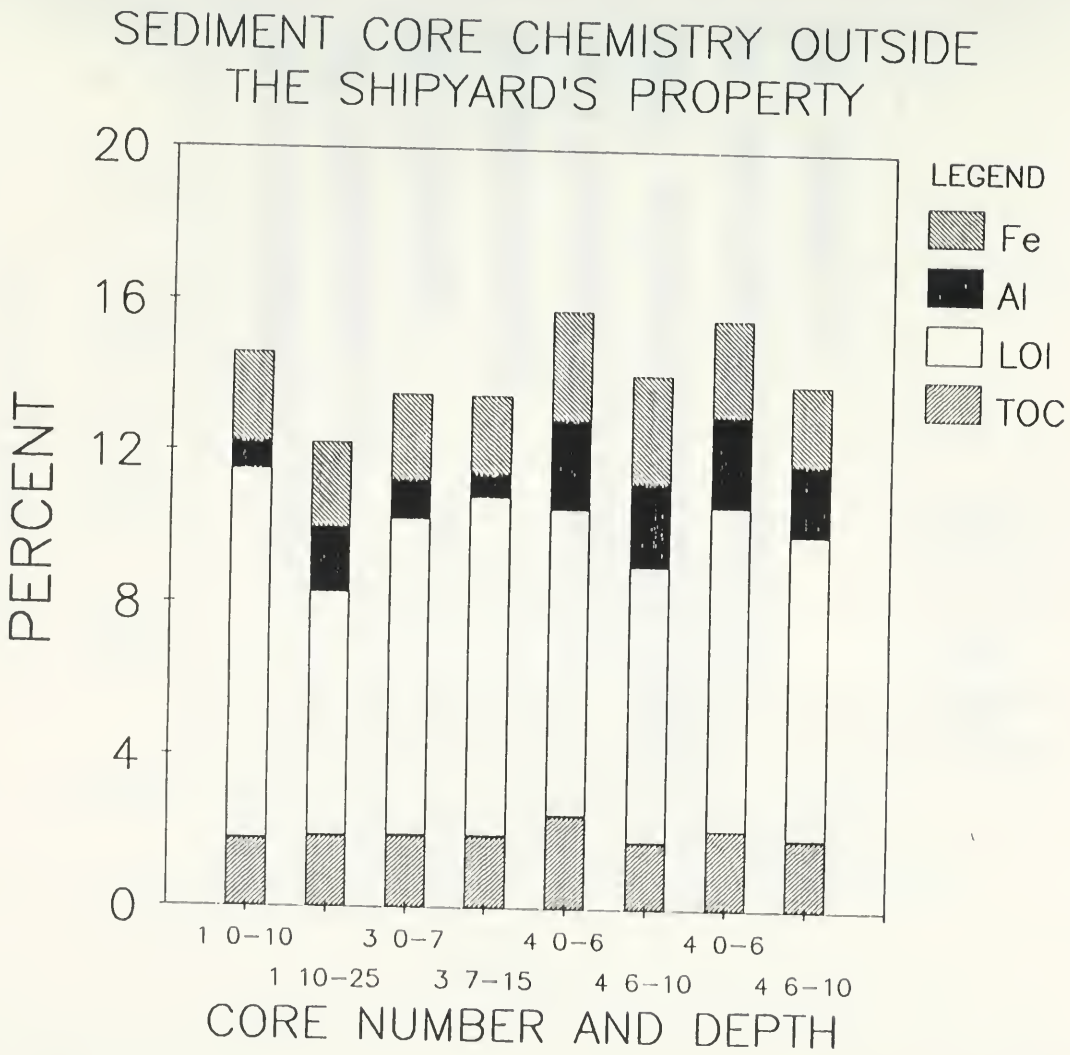

SEDIMENT CORE CHEMISTRY OUTSIDE THE SHIPYARD'S PROPERTY
PERCENT
20
16
12
8
4
0
LEGEND
Fe
Al
LOI
TOC
1 0–10
1 10–25
3 0–7
3 7–15
4 0–6
4 6–10
4 0–6
4 6–10
CORE NUMBER AND DEPTH

FIGURE 6C

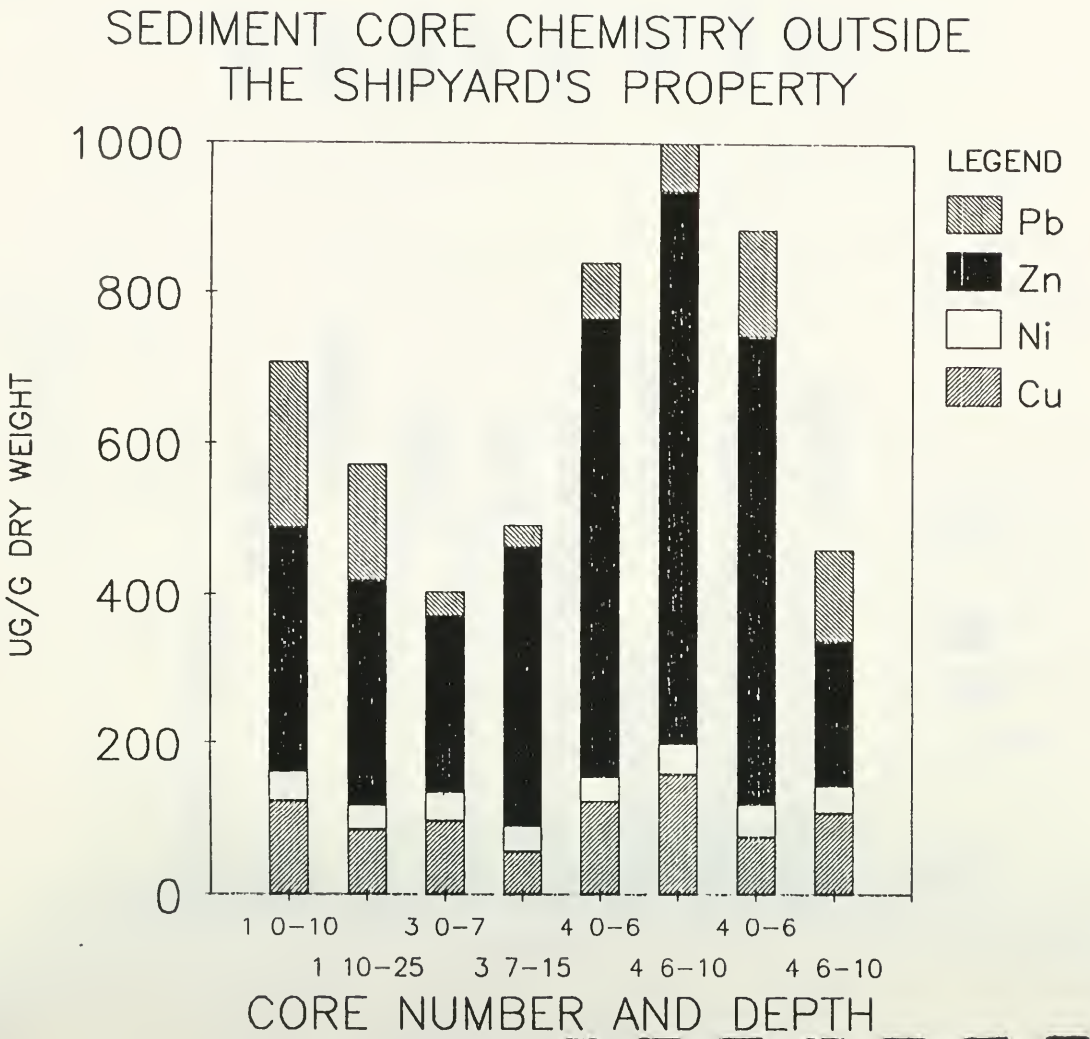

SEDIMENT CORE CHEMISTRY OUTSIDE
THE SHIPYARD'S PROPERTY
1000
800
600
400
200
0
UG/G DRY WEIGHT
LEGEND
Pb
Zn
Ni
Cu
1 0-10
1 10-25
3 0-7
3 7-15
4 0-6
4 6-10
4 0-6
4 6-10
CORE NUMBER AND DEPTH

FIGURE 7A

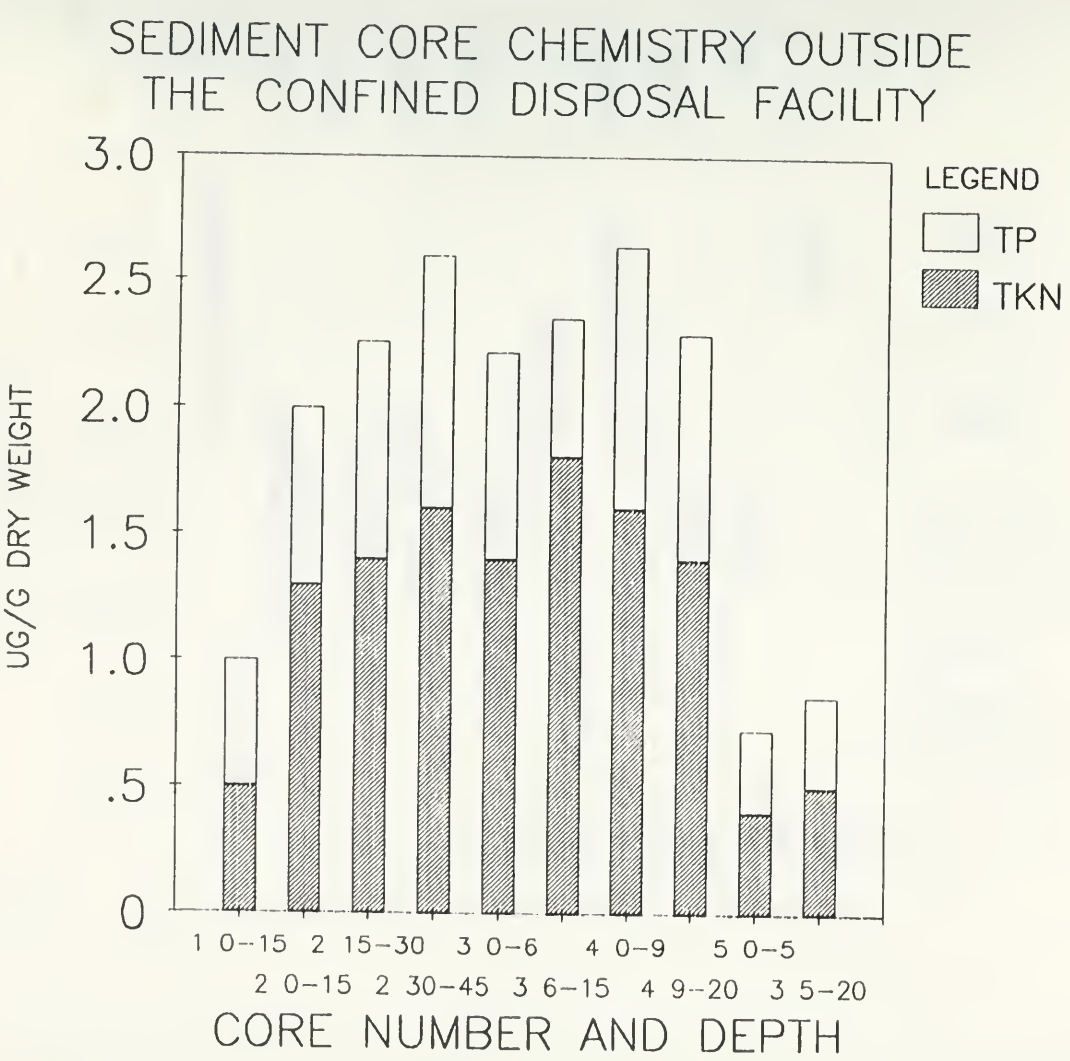

SEDIMENT CORE CHEMISTRY OUTSIDE
THE CONFINED DISPOSAL FACILITY
3.0
2.5
2.0
1.5
1.0
.5
0
UG/G DRY WEIGHT
LEGEND
TP
TKN
1 0-15
2 15-30
3 0-6
4 0-9
5 0-5
2 0-15
2 30-45
3 6-15
4 9-20
3 5-20
CORE NUMBER AND DEPTH

FIGURE 7B

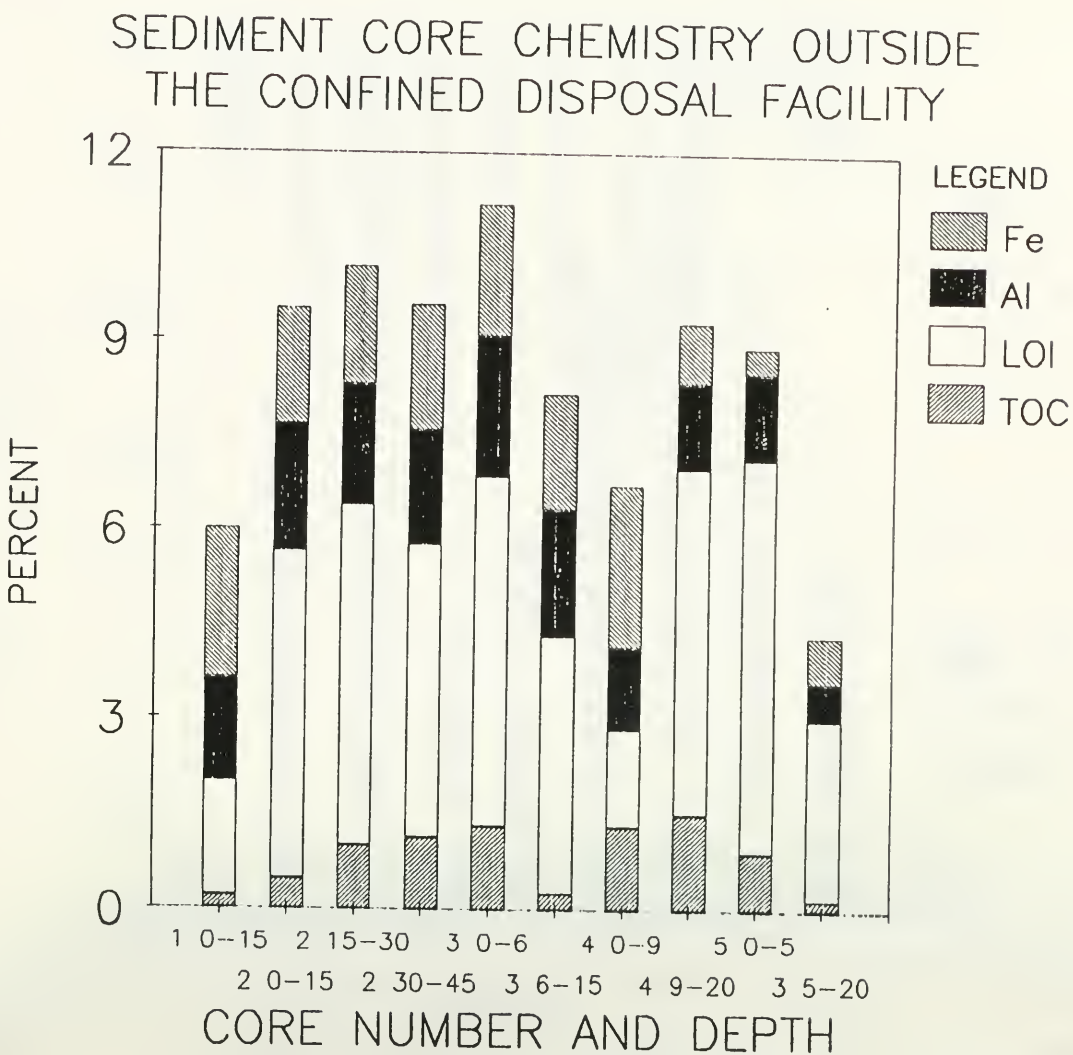

SEDIMENT CORE CHEMISTRY OUTSIDE THE CONFINED DISPOSAL FACILITY
12
9
6
3
0
PERCENT
LEGEND
Fe
Al
LOI
TOC
1 0--15
2 15-30
3 0-6
4 0-9
5 0-5
2 0-15
2 30-45
3 6-15
4 9-20
3 5-20
CORE NUMBER AND DEPTH

FIGURE 7C

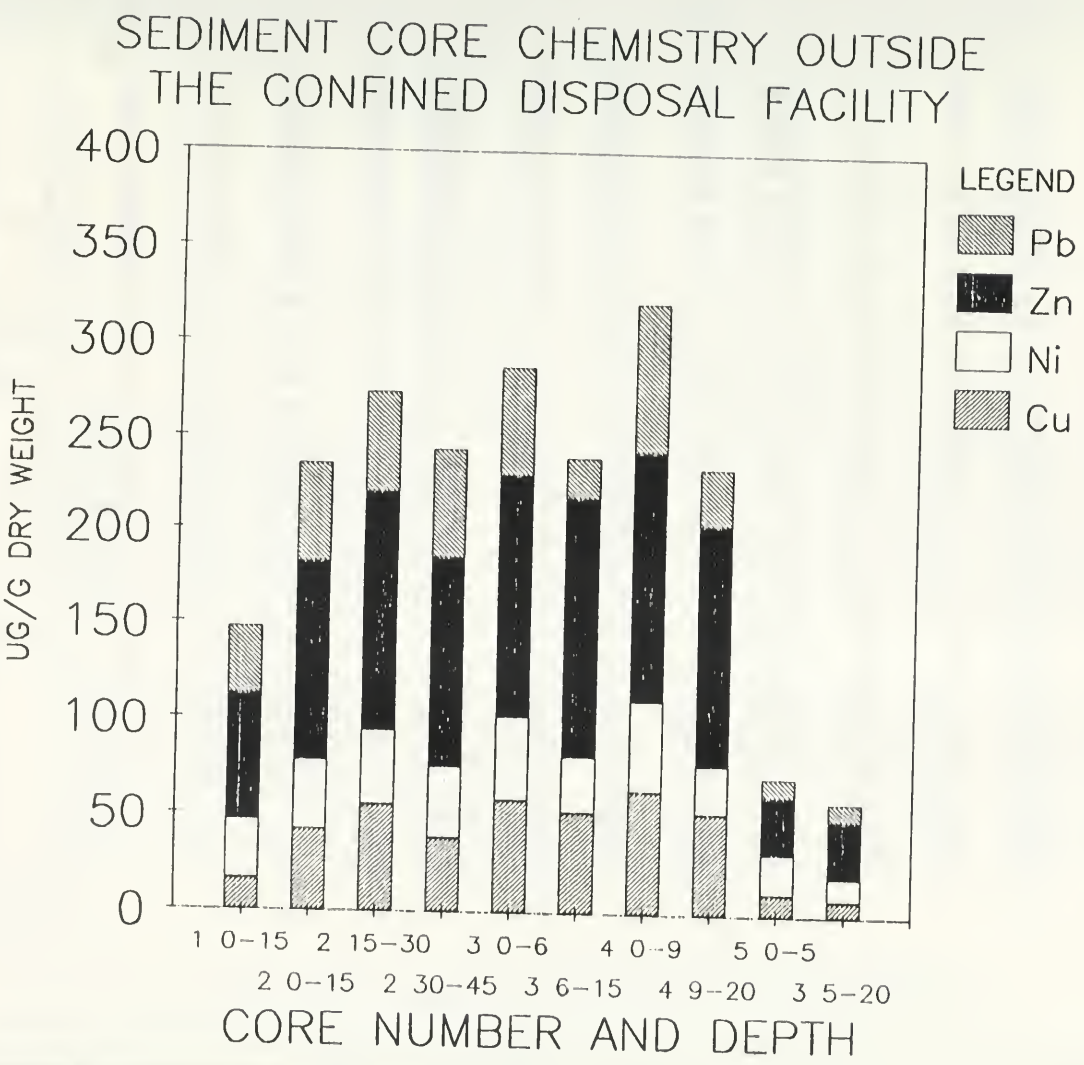

SEDIMENT CORE CHEMISTRY OUTSIDE THE CONFINED DISPOSAL FACILITY
UG/G DRY WEIGHT
400
350
300
250
200
150
100
50
0
LEGEND
Pb
Zn
Ni
Cu
1 0-15
2 15-30
3 0-6
4 0-9
5 0-5
2 0-15
2 30-45
3 6-15
4 9-20
3 5-20
CORE NUMBER AND DEPTH

TABLE 2. ALL VALUES ARE IN UG.G^{-1} DRY WEIGHT.

METAL CHEMISTRY OF SEDIMENT CORES FOR STATIONS USED IN BIOASSAYS

STATION	DEPTH (cm)	Cu	Ni	Pb	Zn	Fe	Mn	P	TKN	Al	Cd	Cr	Hg	TOC
20	2	92	18	45	88	14000	460	1.07	1.59	11000	0.74	21	0.07	13
20	2	33	16	41	85	14000	400	1.24	1.90	9200	0.78	22	0.08	23
20	2	33	18	45	89	15000	470	0.57	0.67	12000	0.88	21	0.07	20
20	4	31	17	42	84	14000	450	1.20	1.61	9400	0.79	19	0.06	15
20	4	35	18	43	87	14000	460	1.15	1.65	10000	0.89	20	0.05	20
20	4	34	19	46	88	14000	460	1.23	1.77	11000	0.88	22	0.08	16
20	6	32	18	44	89	15000	470	1.26	1.81	12000	0.91	21	0.10	19
20	6	32	17	44	83	14000	450	1.13	1.52	11000	0.92	20	0.11	16
20	8	30	17	44	82	15000	460	1.03	1.36	11000	0.90	20	0.12	17
20	8	32	17	45	86	14000	460	1.08	1.48	11000	0.92	19	0.10	13
20	8	30	18	45	83	16000	470	0.96	1.27	13000	0.85	21	0.10	15
20	8	33	18	42	78	15000	460	0.95	1.17	11000	0.82	22	0.10	12
20	10	31	18	47	84	14000	450	1.53	1.91	11000	0.78	21	0.12	12
20	10	29	17	42	79	15000	460	1.30	1.78	11000	0.82	19	0.11	32
20	10	28	17	41	74	15000	470	1.29	1.75	11000	0.81	19	0.09	12
20	14	30	16	43	78	13000	420	1.32	1.87	9600	0.83	19	0.13	25
20	14	31	17	49	90	14000	450	1.48	1.90	11000	0.80	20	0.07	16
20	14	34	17	55	91	14000	440	1.16	1.58	10000	0.81	19	0.08	13
20	18	35	18	50	93	15000	460	1.73	2.42	11000	0.86	19	0.11	20
21	2	50	20	90	160	16000	460	2.44	3.48	11000	0.91	24	0.14	23
21	2	52	20	88	170	16000	460	2.56	3.71	12000	0.96	25	0.15	26
21	2	52	19	86	160	16000	450	2.73	3.87	11000	0.94	23	0.31	21
21	4	57	21	100	170	16000	460	2.74	3.11	11000	0.93	27	0.19	24
21	4	52	21	94	160	17000	490	2.38	3.50	12000	0.95	26	0.14	22
21	4	55	22	97	170	17000	480	2.62	3.49	12000	1.00	29	0.15	30
21	6	52	22	80	160	17000	490	2.88	4.13	12000	0.91	27	0.17	21
21	6	59	21	110	180	17000	460	2.94	3.49	11000	1.10	26	0.14	25
21	6	54	20	93	170	17000	480	2.18	3.03	12000	1.00	25	0.11	29
21	8	50	21	79	160	17000	480	1.28	1.92	12000	1.10	26	0.13	26
21	8	52	22	87	170	18000	490	1.37	2.11	12000	1.10	26	0.13	25
21	8	50	22	80	160	17000	480	1.66	2.49	12000	0.93	26	0.17	24

METAL CHEMISTRY OF SEDIMENT CORES FOR STATIONS USED IN BIOASSAYS

STATION	DEPTH (cm)	Cu	Ni	Pb	Zn	Fe	Mn	P	TKN	Al	Cd	Cr	Hg	TOC
21	10	49	21	79	150	17000	480	1.54	2.20	12000	0.94	25	0.12	19
21	10	50	19	72	170	19000	470	1.54	2.41	11000	0.91	28	0.13	24
21	10	50	21	84	160	19000	490	1.63	2.49	13000	1.10	27	0.11	20
21	14	52	23	97	170	19000	500	1.67	2.38	14000	1.10	30	0.09	22
21	14	54	21	100	180	18000	480	1.86	2.27	12000	1.10	28	0.14	25
21	14	55	22	99	180	19000	490	1.48	1.88	12000	1.10	28	0.15	25
21	18	61	20	150	210	19000	480	1.88	1.72	13000	1.20	31	0.14	26
21	18	54	19	140	150	17000	460	1.65	1.93	11000	1.10	23	0.13	21
21	18	54	20	140	160	18000	470	1.75	1.86	12000	1.10	28	0.17	20

MEAN VALUES:

STATION	DEPTH	Cu	Ni	Pb	Zn	Fe	Mn	P	TKN	Al	Cd	Cr	Hg	TOC
20	2	32.667	17.333	43.667	86.667	14333.3	443.3	0.960	1.387	10733	0.793	21.333	0.073	18.667
	4	33.333	18.000	43.667	86.333	14000.0	456.7	1.193	1.677	10133	0.853	20.333	0.063	17.000
	6	31.333	17.333	44.000	84.667	14666.7	460.0	1.140	1.563	11333	0.910	20.333	0.110	17.333
	8	31.667	17.667	44.000	82.333	15000.0	463.3	0.997	1.307	11667	0.863	20.667	0.100	13.333
	10	29.333	17.333	43.333	79.000	14666.7	460.0	1.373	1.813	11000	0.803	19.667	0.107	18.667
	14	31.667	16.667	49.000	86.333	13666.7	436.7	1.320	1.783	10200	0.813	19.333	0.093	18.000
	18	35.000	18.000	50.000	93.000	15000.0	460.0	1.730	2.420	11000	0.860	19.000	0.110	20.000

STATION	DEPTH	Cu	Ni	Pb	Zn	Fe	Mn	P	TKN	Al	Cd	Cr	Hg	TOC
21	2	51.333	19.667	88.000	163.333	16000	456.667	2.577	3.620	11333	0.937	24.000	0.200	23.333
	4	54.667	21.333	97.000	166.667	16667	476.667	2.580	3.367	11667	0.960	27.333	0.160	25.333
	6	55.000	21.000	94.333	170.000	17000	476.667	2.667	3.550	11667	1.003	26.000	0.140	25.000
	8	50.667	21.667	82.000	163.333	17333	483.333	1.437	2.173	12000	1.043	26.000	0.143	25.000
	10	49.667	20.333	78.333	160.000	18333	480.000	1.570	2.367	12000	0.983	26.667	0.120	21.000
	14	53.667	22.000	98.667	176.667	18667	490.000	1.670	2.177	12667	1.100	28.667	0.127	24.000
	18	56.333	19.667	143.333	173.333	18000	470.000	1.760	1.837	12000	1.133	27.333	0.147	22.333

TABLE 3. METALS AND PCBs IN FATHEAD MINNOWS USED IN SEDIMENT BIOASSAYS. ALL VALUES ARE IN UG.G^{-1}. TOP5 REFERS TO THE SURFICIAL 5 CM, BULK REFERS TO HOMOGENIZED CONTENTS OF ENTIRE PONAR GRABS, AND CORE REFERS TO INTACT SEDIMENT CORES.

TREATMENT	SEDIMENT	DRY/WET	Al	As	Cd	Cr	Cu	Fe	Pb
top5	culture	0.2125	4.10	0.131	0.005	0.120	2.43	18	0.051
bulk	control	0.2055	77.70	0.177	0.014	0.260	2.03	161	0.188
bulk	20	0.1716	30.80	0.149	0.011	0.180	1.78	63	0.568
core	20	0.1929	26.10	0.464	0.041	0.660	4.08	417	3.161
top5	20	0.2081	79.90	0.194	0.015	0.260	3.72	168	0.620
top5	20	0.2171	67.30	0.145	0.040	0.320	3.36	135	0.602
top5(mean)	20	0.2126	73.60	0.170	0.028	0.290	3.54	152	0.611
bulk	21	0.1970	93.50	0.170	0.020	0.370	2.52	202	1.999
core	21	0.2180	243.50	0.448	0.055	0.590	4.19	476	3.329
core	21	0.2140	155.80	0.353	0.037	0.480	3.39	302	1.834
core(mean)	21	0.2160	199.65	0.401	0.046	0.535	3.79	389	2.582
top5	21	0.2168	75.10	0.158	0.019	0.380	3.39	172	0.810
bulk	21	0.1863	43.40	0.207	0.014	0.220	1.99	98	0.448
bulk	387	0.2015	23.10	0.194	0.013	0.130	2.36	63	0.127

METALS AND PCBs IN FATHEAD MINNOW BIOASSAYS

TREATMENT	SEDIMENT	Mn	Hg	Ni	Zn	PCB	Aldry	Asdry	Cddry
top5	culture	0.61	0.115	0.00	39.9	0.10	19.3	0.616	0.024
bulk	control	5.21	0.099	0.29	34.7	0.52	378.1	0.861	0.068
bulk	20	1.90	0.079	0.15	27.0	0.15	179.5	0.868	0.064
core	20	11.25	0.085	0.75	36.5	0.29	172.1	2.405	0.213
top5	20	5.00	0.106	0.32	44.8	0.19	384.0	0.932	0.072
top5	20	4.02	0.098	0.31	40.6		310.0	0.668	0.184
top5(mean)	20	4.51	0.102	0.32	42.7	0.19	347.0	0.800	0.128
bulk	21	5.79	0.091	0.43	32.2	0.24	474.6	0.883	0.102
core	21	13.94	0.088	0.97	43.9	0.19	1117.0	2.055	0.252
core	21	8.77	0.094	0.57	33.4		728.0	1.650	0.173
core(mean)	21	11.36	0.091	0.77	38.7	0.19	922.5	1.852	0.213
top5	21	4.55	0.094	0.79	40.5	0.25	343.2	0.722	0.087
bulk	21	3.08	0.081	0.17	27.3	0.21	233.0	1.111	0.075
bulk	387	2.23	0.087	0.18	35.9	0.20	#VALUE!	0.963	0.065

METALS AND PCBs IN FATHEAD MINNOW BIOASSAYS

TREATMENT	SEDIMENT	Crdry	Cudry	Fedry	Pbdry	Mndry	Hgdry	Nidry	Zndry	PCBdry
top5	culture	0.565	11.435	84.706	0.240	2.871	0.541	0.000	187.8	0.47
bulk	control	1.265	9.878	783.455	0.915	25.353	0.482	1.411	168.9	2.53
bulk	20	1.049	10.373	367.139	3.310	11.072	0.460	0.874	157.3	0.87
core	20	3.421	21.151	2161.742	16.387	58.320	0.441	3.888	189.2	1.50
top5	20	1.249	17.876	807.304	2.979	24.027	0.509	1.538	215.3	0.91
top5	20	1.474	15.477	621.833	2.773	18.517	0.451	1.428	187.0	
top5(mean)	20	1.362	16.676	714.569	2.876	21.272	0.480	1.483	201.1	0.91
bulk	21	1.878	12.792	1025.381	10.147	29.391	0.462	2.183	163.5	1.22
core	21	2.706	19.220	2183.486	15.271	63.945	0.404	4.450	201.4	0.87
core	21	2.243	15.841	1411.215	8.570	40.981	0.439	2.664	156.1	
core(mean)	21	2.475	17.531	1797.351	11.920	52.463	0.421	3.557	178.7	0.87
top5	21	1.737	15.494	786.106	3.702	20.795	0.430	3.611	185.1	1.14
bulk	21	1.181	10.682	526.033	2.405	16.532	0.495	0.913	146.5	1.13
bulk	387	0.645	11.712	312.655	0.630	11.067	0.432	0.893	176.2	0.99

TABLE 4. METALS AND PCBS IN MAYFLY NYMPHS USED IN SEDIMENT BIOASSAYS. ALL VALUES ARE IN UG.G^{-1}. TOP5 REFERS TO THE SURFICIAL 5 CM, BULK REFERS TO HOMOGENIZED CONTENTS OF ENTIRE PONAR GRABS, AND CORE REFERS TO INTACT SEDIMENT CORES.

TREATMENT	SEDIMENT	DRY/WET	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni
top5	culture	0.1228	200.4	0.085	0.091	0.46	1.70	355	0.49	21.03	0.005	0.43
bulk	control	0.1034	303.3	0.163	0.074	0.68	1.62	528	0.76	27.41	0.005	0.74
bulk	20	0.1309	215.3	0.195	0.083	0.53	2.98	445	2.45	16.70	0.008	0.84
core	20	0.1110	233.2	0.197	0.043	0.58	3.23	440	2.82	12.73	0.008	0.86
top5	20	0.1270	192.2	0.226	0.088	0.50	2.83	384	2.18	13.26	0.009	0.84
bulk	21	0.1052	161.3	0.167	0.061	0.46	2.64	331	2.47	12.73	0.008	0.68
core	21	0.1149	218	0.239	0.047	0.46	2.83	437	1.98	13.91	0.009	0.75
top5	21	0.1186	212.3	0.246	0.091	0.56	3.09	414	2.83	13.74	0.009	0.79
bulk	26	0.1115	162.2	0.582	0.061	0.43	2.51	314	1.53	11.06	0.010	0.69
bulk	26	0.1174	198.2	0.747	0.063	0.51	3.03	394	1.89	14.84	0.006	0.79
bulk(mean)	26	0.1145	180.2	0.665	0.062	0.47	2.77	354	1.71	12.95	0.008	0.74
bulk	387	0.1160	153.9	0.273	0.054	0.33	1.99	340	0.77	10.29	0.005	0.77

METALS AND PCBs IN MAYFLY NYMPH BIOASSAYS

TREATMENT	SEDIMENT	Zn	PCB	Aldry	Asdry	Cddry	Crdry	Cudry	Fedry	Pbdry	Mndry	Hgdry
top5	culture	24.9	0.09	1631.92	0.69	0.74	3.75	13.84	2890.88	3.97	171.25	0.041
bulk	control	19.6	0.39	2933.27	1.58	0.72	6.58	15.67	5106.38	7.32	265.09	0.048
bulk	20	25.2	0.32	1644.77	1.49	0.63	4.05	22.77	3399.54	18.71	127.58	0.061
core	20	21.6	0.15	2100.90	1.77	0.39	5.23	29.10	3963.96	25.40	114.68	0.072
top5	20	23.4	0.23	1513.39	1.78	0.69	3.94	22.28	3023.62	17.17	104.41	0.071
bulk	21	22.1	0.22	1533.27	1.59	0.58	4.37	25.10	3146.39	23.48	121.01	0.076
core	21	21.2	0.17	1897.30	2.08	0.41	4.00	24.63	3803.31	17.22	121.06	0.078
top5	21	26.5	0.23	1790.05	2.07	0.77	4.72	26.05	3490.73	23.85	115.85	0.076
bulk	26	21.9		1454.71	5.22	0.55	3.86	22.51	2818.14	13.72	99.19	0.090
bulk	26	21.2	0.22	1688.25	6.36	0.54	4.34	25.81	3356.05	16.06	126.41	0.051
bulk(mean)	26	21.6	0.22	1571.48	5.79	0.54	4.10	24.16	3086.10	14.89	112.80	0.070
bulk	387	20.0	0.09	1326.72	2.35	0.47	2.84	17.16	2931.03	6.63	88.71	0.043

METALS AND PCBs IN MAYFLY NYMPH BIOASSAYS

TREATMENT	SEDIMENT	Nidry	Zndry	PCBdry
top5	culture	3.50	202.77	0.73
bulk	control	7.18	189.56	3.77
bulk	20	6.42	192.51	2.44
core	20	7.75	194.59	1.35
top5	20	6.61	184.25	1.81
bulk	21	6.46	210.08	2.09
core	21	6.53	184.51	1.48
top5	21	6.66	223.44	1.94
bulk	26	6.19	196.41	
bulk	26	6.73	180.58	1.87
bulk(mean)	26	6.46	188.50	1.87
bulk	387	6.64	172.41	0.78

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

Canada-Ontario Agreement Respecting Great Lakes Water Quality
L'Accord Canada-Ontario relatif à la qualité de l'eau dans les Grand Lacs